Combined Ultraviolet Studies of Astronomical Sources

NASA Grant NAG5-87

Semiannual Progress Report No. 6

For the Period 1 February 1983 through 31 July 1983

Principal Investigators

Drs. A. K. Dupree; M. S. Giampapa; J. P. Huchra; R. W. Noyes;
L. W. Hartmann; J. C. Raymond; W. P. Blair; G. D. Bothun;
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October 1983

Prepared for
National Aeronautics and Space Administration
Greenbelt, MD 20771

Smithsonian Institution
Astrophysical Observatory
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Ultraviolet Spectra of Non-Radiative Shock Waves

Two Short Wavelength Prime (SWP) images of a nonradiative shock in the Cygnus Loop were analyzed. The results were used with high and low resolution optical spectra and new model calculations to determine the shock velocity, pre-shock ionization state and elemental abundances in the gas. The data suggest that electron-ion equilibration is dominated by Coulomb collisions rather than rapid plasma turbulence processes. A paper is in press.

Grain Destruction and Elemental Abundances in Interstellar Shocks

Spectra of G65.2+5.7 and two new positions in the Vela Supernova remnant were obtained, all showing modest shock velocities. Further interpretation awaits new model calculations (nearly complete) and complementary optical spectroscopy. Spectra spanning the region of Miller's position 3 in the Cygnus Loop have been obtained. We are developing models of a blastwave-cloud interaction to interpret them. Spectra of a new position in the SE Cygnus Loop were obtained as part of a large UV optical, radio, X-ray collaboration. The young SNR in NGC 4449 was observed. The lower limit on I(O III λ1662)/I(C III λ1909) provides a lower limit on the oxygen to carbon abundance ratio and a lower limit to the mass of the progenitor.

Carbon Abundance in M33 and M31 from Supernova Remnants

The purpose of this program was to use three US1-US2 shift pairs to obtain long SWP exposures on several of the brightest and least reddened supernova remnants (SNRs) in M33 and M31. These observations would then be used in conjunction with shock model calculations todetermine the carbon abundances in the interstellar mediums of these galaxies. Three M33 SNRs were observed, with the exposures being terminated in each case before the end of the

US1 shift due to unusually high background levels. Hence, only upper limits on the important C III] λ1909 and C IV λ1550 lines were obtained in each case.

Even though the carbon lines were not detected, the upper limits provide some useful information. We have predicted the expected intensity of the C III] line using shock models that were calculated assuming solar abundances and using previous optical observations of the SNRs. In all three cases, the upper limits on C III] are a factor of two to three below the expected value, indicating at least qualitatively that the carbon abundance is lower in M33. Perhaps more importantly, this comparison also indicates that the ratio of carbon to oxygen may be lower in M33 than in our Galaxy. This would affect abundance gradient analyses for M33 which, up to now, have had to assume the galactic C/O ratios. A sixth round collaboration using ESA/US1 shift pairs to obtain long exposures will allow these results to be quantified.

Determination of the Mass Function in the Large Magellanic Cloud

In June and August 1982 SWP spectra of 21 stars in the young LMC Associations No. 77 and 96. These data have all been reduced. Preliminary analysis suggests that most of thees stars are in the spectral range B0 to A0 and are of luminosity class I (Ia) or III. These stars have apparent magnitudes of 10 - 13 (corresponding to a range in absolute magnitude of -8.5 to -5.5). There is an anti-correlation between absolute visual magnitude and surface temperature (spectral type) in our data. This is consistent with observing stars of approximately constant bolometric luminosity (M_{bol} = -9). As of yet we have not reached the main-sequence. The data shows that both of these Associations are rich in massive, evolved stars which implies a young Association (less than 10^7 years old) and a shallow IMF. The majority of stars have spectral types in the range B0 III - B3 III.

In addition, stars in Association 96 are more strong-lined and show pro-

nounced evidence for mass-loss. In particular, one star, of spectral type B0, has a wind with a terminal velocity of ~ 3000 km s^{-1}. The implication arises that the metal abundance is higher in Association No. 96 than 77. Further observations of stars in Association 96 are needed in order to verify this implication.

UV Spectrophotometry of Hot Galaxies

So far one exposure has been taken on this program. However, the SWP spectrum of Mk 487 was underexposed because the particle background rose dramatically 2 hours before the end of the shift. A paper is being written on the short-wavelength spectra of two high-redshift galaxies observed previously.

UV Spectra of White Dwarf Pulsars

Observations have been obtained around the binary orbits of three X-ray-emitting "DQ Herculis" stars: H2215-086, YY Draconis, and AC Cancri. All show more or less the "standard" ultraviolet spectrum for a cataclysmic variable. Preliminary analysis of the first indicates that both the emission lines and the continuum seen in the SWP exposures are strongly pulsed with the optical period of 21 minutes. This locates the emitting region near the center of the disk, where temperatures are high. Spectra of AC Cancri showed that the C IV emission line is much weaker and narrower in eclipse. This demonstrates that most of the emission originates in the accretion disk, not in an outflowing wind as previously thought. An outflowing wind can contribute at most one-fourth of the emission-line flux.

Stellar Flares

During November 1982 we organized observations for three chromospherically-active M-type dwarf stars for flares both in the ultraviolet

with IUE and in the visible at the F.L. Whipple Observatory. We observed UV Ceti (dM5e), YY Gem (dM1e) and Gliese 815 (dM3e) with IUE, while inclement weather precluded the planned spectrophotometry at Hα and Hβ from the ground-based telescope. None of the stars showed significant enhancements, that is, larger than about 20%, in the ultraviolet emission flux of C IV λ1550. Analysis of the quiescent level of emissions is ongoing. Comparison of the chromospheric and transition-region fluxes with the quiescent and flare spectra of other dMe stars reveals that the increased radiative output during flares is comparable in both the transition region and chromosphere. Our previous flare observations of EQ Peg (Fourth-Year proposal) show no brightening of the material above a temperature of about 2 x 10^5K, as indicated by the lack of enhancement of N V λ1240 and He II λ1640. Energy input requirements from the flare and/or flare mechanism, beyond the energy required to heat the quiescent chromosphere and transition region, is thus confined to the atmospheric layers of C IV (temperature of 1 x 10^5K) and below. The behavior of the chromospheric and transition-region emission line enhancements is reminiscent of that of solar surges.

Variability of the Double Quasar Q0957+56'AB

The double quasar was observed in May 1982 to suffer a weakening of the B component. In June/July 1982 the B component revived and remained stable through December 1982. Results of line and continuum measurements were reported at the Cambridge Conference on Gravitational Lenses in December 1982, and a paper is in preparation that will incorporate the ongoing VLA monitoring of the source.

A major part of this effort is that of software. The reduction scheme for separating two closely spaced LWP images with very low signal-to-noise has been completed and tested at various exposure levels and wavelength binning

intervals. Additionally, we have compared several images with another reduction program written independently at Goddard. The agreement between the two gives confidence in our code. As part of this procedure we made a calibration in LWP camera using standard stars observed with both LWP and LWR spectrographs.

Spectra of Late-F Dwarfs and Their Relation to Rotation

Data acquisition is now complete for this project to study how chromospheric and transition region emission depends on stellar mass and rotational velocity for F dwarfs. Since many spectra were obtained at the end of the IUE year, data reduction is still in progress. The data examined so far demonstrates how sensitive to mass this emission is. Stars with similar rotational velocities, but different masses, show very different levels of emission. This emission drops rapidly as the outer convective zones of these stars decreases with increasing mass. This ultraviolet data provides an indication of the chromospheric properties of these relatively hot stars that cannot be obtained from optical data.

Dynamics of Hot Gas Surrounding Hybrid Stars

We have derived emission measure distributions for the hybrid stars using the UV line fluxes observed plus the pressure indicated from two long exposures of the C II density-sensitive lines in αTrA. The results clearly demonstrate the existence of a spatially extended transition-region in which the conductive flux cannot balance the radiative losses alone. However, the temperature gradients are considerably steeper than predicted by the simple Hartmann-MacGregor wind models. This work will be submitted for publication shortly.

High Resolution Study of Epsilon Coronae Austrinae

Observations were made at critical phases to obtain well separated line

profiles of this contact eclipsing binary system. Inspection of the photorite shows an asymmetric profile of Lyman-α that is typical of mass outflow. The spectrum is weak and a detailed hand reduction is in progress on our image processing system. Detection of mass outflow would be the first time direct evidence for a stellar wind has been discovered in these W UMa-type systems. Estimate of the rate of mass loss and hence momentum loss and braking would be important confirming evidence for the evolutionary sequence of these systems.

Active Regions on Solar-type Dwarfs as a Function of Rotation Rate and Age

In the program we obtained ultraviolet spectra of a number of late-type dwarf stars with known rotation rates, in close coordination with ground-based observations of the same stars as part of the ongoing program of stellar Ca II (H and K) rotational modulation observations. A specific goal was to obtain UV emission fluxes at times of minimum and maximum Ca II activity, reflecting minimum and maximum levels of surface activity on the facing hemisphere of the star.

In analyzing our results, we found enhancements of 30-50% in the transition-region lines compared to 5-7% in the chromospheric Ca II and Mg II emission enhancements. The degree of enhancement of N V 1240, C IV 1550, and He II 1640 at times of high Ca II emission suggests that active regions on other G and K type dwarfs are rather similar to those on the Sun. These results were reported at the IAU Symposium No. 102, "Solar and Stellar Magnetic Fields: Origins and Coronal Effects" (Baliunas *et al.* 1982).

We have used the Mg II fluxes observed under this program, along with additional IUE data made available through the National Space Science Data Center, to investigate the relation between overall chromospheric emission rotation, and spectral type among lower main sequence stars (Hartmann *et al.* 1983). This work complements and extends a related study of the dependence of Ca II

emission on rotation and spectral type, which suggested a tight relation between chromospheric activity and the ratio of rotation period to convective overturn time near the bottom of the convection zone. A strong dependence on convection zone properties is also inferred from the Mg II data, particularly for F and early G dwarfs with shallower convection zones than late G and K dwarfs. An important point is that the Mg II data are relatively free of contamination from photospheric emission, in contrast (particularly for the arlier spectral types) to the available Ca II flux data.

Coordinated Chromospheric Synoptic Observations of Selected Late-type Stars

We have utilized the eight shifts allocated to this program. Unfortunately this program was severely hampered by poor weather. During clear conditions in July 1982, observations of two of the program targets indicated no detectable magnetic fields. A preliminary inspection of the IUE data acquired at this time revealed no discernable UV variability in the program targets. A subsequent run in November 1982 was thwarted by a storm system that prevented the acquisition of the ground-based data. However, the IUE observations revealed the possible presence of line profile and flux variability in the chromospheric lines of some program targets. We are presently analyzing these data and preliminary results for ϵ Eri show profile variability in the Mg II h and k lines. This variability may be due to variable velocity fields in the region of k_2, h_2 formation. Fortunately, we have been allocated eight additional US2 shifts for this program. We have scheduled simultaneous ground and IUE observations for January 13-20, 1984.

The Two-Component Atmosphere of Lambda Andromedae

The chromospherically-active G8 IV-III star λ And was observed with IUE during its 54-day rotation period at two phases corresponding to times of maximum and minimum area covered by starspots and their associated active regions. The line profiles taken at high resolution of the transition-region emissions are unusually broad, with velocities much larger than expected from the thermal widths. We are continuing analysis of the widths and asymmetries present in the chromospheric and transition-region profiles, and find the profiles consistent with a warm, expanding wind in the upper atmosphere of the star. During our monitoring, we also recorded a flare in the ultraviolet emission from λ And (submitted to *Ap.J.*, May 1983). Enhancements of factors of several for C IV λ1550, C III λ1175 and other high-temperature lines persisted over six hours. This flare was over a million times more energetic than typical solar flares. This was the first stellar flare for which the Mg II h and k (λ2800) and H I Ly α (λ1215) chromospheric lines were measured along with the transition-region fluxes in both the quiescent and flare states. The energy radiated by the chromospheric features is comparable to that of the transition-region lines. The appearance of an ultraviolet continuum during the flare has eliminated some theoretical stellar flare models that predict particular energy distributions in the ultraviolet.

Activity in Hyades Giants

The giant stars in the Hyades present a well-studied group of stars of spectral type K O III. Their visible-light properties are similar, if not identical. All appear to be rotating slowly. Yet, from a previous IUE study, their chromospheric and coronal emission is different, one from the other, by as much as a factor of ten (Baliunas, Hartmann, and Dupree 1983, *Ap. J.*, in press). Since

these presumably coeval,homogeneous stars are similar in macroscopic parameters thought to control chromospheric and coronal emission, our fifth-year IUE program began a search for variability over long timescales. We conjectured that this disparity in emissions strengths results from different phases of activity cycles--much as is present in dwarf stars. Our measurements from March 1982, combined with our earlier observations reveal no significant flux variations larger than about 20% over the past three years. We are planning to continue monitoring these giants for possible activity-cycle variations in the upcoming year.

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